

Improving the MODIS Global Snow-Mapping Algorithm

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Abstract -- An algorithm (Snowmap) is under development to produce global snow maps at 500 meter resolution on a daily basis using data from the NASA MODIS instrument. MODIS, the Moderate Resolution Imaging Spectroradiometer, will be launched as part of the first Earth Observing System (EOS) platform in 1998. Snowmap is a fully automated, computationally frugal algorithm that will be ready to implement at launch. Forests represent a major limitation to the global mapping of snow cover as a forest canopy both obscures and shadows the snow underneath. Landsat Thematic Mapper (TM) and MODIS Airborne Simulator (MAS) data are used to investigate the changes in reflectance that occur as a forest stand becomes snow covered and to propose changes to the Snowmap algorithm that will improve snow classification accuracy forested areas.

INTRODUCTION

In the Northern Hemisphere winter, over 40% of the globe may be covered with seasonal snow. The high albedo of snow coupled with its large areal extent make it a strong influence on the Earth's radiation budget. Snow cover also has important societal ramifications. Runoff from snowmelt is an important water resource in many regions of the world and heavy late season snowfalls can cause disastrous flooding [1]. However monitoring of snow cover extent is not currently performed on a global basis.

MODIS, The Moderate Resolution Imaging Spectroradiometer, is scheduled for launch in 1998 aboard the first NASA Earth Observing System (EOS) platform. MODIS is designed to provide quantitative measurements of important geophysical parameters on a global basis [2]. Its high spatial resolution and numerous spectral bands in the 0.4 to 2.5 μm wavelength region allow for more accurate monitoring of snow cover than is possible using currently operational satellites. A prototype algorithm (Snowmap) has been developed to produce daily snow maps with 500 meter resolution at the global scale using MODIS visible to short-wave infrared reflectances [3].

Aside from cloud cover, forests present the most serious limitation to monitoring snow-cover extent using visible to short-wave infrared satellite imagery as much of the world's seasonally snow-covered area contains forests. For example, in North America 40% of the area north of the continental

snowline is forest covered. Validation efforts using Landsat Thematic Mapper (TM) and MODIS Airborne Simulator (MAS) images indicate that classification accuracy in forests, especially dense forests, is lower than in biomes where vegetation is sparse or of low stature. Because of their large extent, accurate snow mapping in forests is vital to maximize the accuracy of mapping snow cover in forests.

THE SNOWMAP ALGORITHM

Snowmap is a fully automated and computational frugal algorithm that will be ready to implement by the launch of the EOS AM-1 spacecraft in 1998 [3]. It builds on nearly on two decades of remote sensing research and represents a significant improvement over existing operational products because of the cloud screening ability of MODIS, its unique spectral bands and the planned 500 m resolution of the future MODIS snow cover products. Snowmap uses at-satellite reflectances in the 0.4 to 2.5 μm wavelengths (Fig. 1) to determine if a pixel is snow-covered using two classification criteria. The first is a Normalized Difference

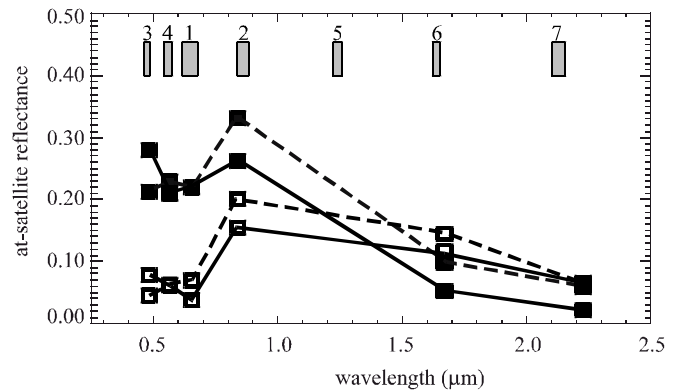


Fig. 1: Observed (solid line) and modeled (dashed line) spectra for a leafless deciduous forest stand. Open symbols are for snow free conditions and filled symbols for snow covered conditions. The model results were produced using the GeoSAIL model for a leafless aspen stand and illumination conditions corresponding to the August and February TM acquisitions. MODIS bands are indicated by the gray boxes

Snow Index (NDSI) value of greater or equal to 0.40. The NDSI is akin to the Normalized Difference Vegetation Index (NDVI) and is calculated using MODIS bands 4 and 6. Such a combination of visible and short-wave infrared wavelengths has a long history of use in snow classification and provides good discrimination of snow over a wide range of conditions. In addition, only pixels with a reflectance at 0.9 μm , (MODIS band 2) of greater than 11% are considered snow. This effectively excludes water which may have high NDSI values.

FOREST STAND REFLECTANCE

A forest canopy affects the stand reflectance as it obscures and shadows the snow cover underneath. Thus the reflectance of a forest stand with a snow cover beneath (a snow-covered forest) will differ considerably from that of a pure snowpack. The reflectance of a forest stand is determined by the reflectance, transmittance, geometry and areal extent of the canopy, properties of the canopy, the areal extent of the canopy, the surface cover and the solar illumination conditions which determine the proportion of shadowed and sunlight areas.

Landsat TM images from Prince Albert National Park, Saskatchewan, and Glacier National Park, Montana, and MAS images from central Alaska were used to observe how the reflectance of snow-covered and snow-free forests differ. GeoSAIL, a forest canopy model [4] was used to investigate how the reflectance of a forest stand would be expected to vary due to changes in the canopy and background, solar zenith angle, and snow grain size. Both observed and modeled spectra of a forest stand indicate a snow cover under a forest canopy will produce significant changes in the spectral reflectance of the forest stand that can be used to distinguish snow-covered from snow-free conditions (Fig. 1).

The most obvious reflectance change is an increase in the visible reflectances. In some species, short-wave infrared (1.6 μm) reflectances may also decrease. Combined, these changes will cause a snow-covered forest to have a higher NDSI than a snow-free forest, though not as high as for a pure snow cover and in many cases too low to be classified as snow in Snowmap. In addition, the red reflectance of forest is closer to its near-infrared reflectance if a snow cover is present. This makes the NDVI for a snow-covered forest lower than that of a snow-free forest.

PROPOSED ADDITIONS TO THE SNOWMAP ALGORITHM

These observed and modeled reflectance differences are used to propose improvements to the current Snowmap algorithm that enable improved detection of snow under forested conditions. To maintain Snowmap's simplicity and frugality and to speed possible implementation, the proposed additions are designed as additions to the existing algorithm, not as a complete redesign of the algorithm.

The first is the addition of a NDSI-NDVI field (Fig. 2) that captures the observed differences between snow-covered and snow-free forests better than does the current algorithm. Taken together, the NDVI and NDSI allow for robust discrimination between snow-free and snow-covered forests. The new field is designed to capture as much of the variation in NDSI-NDVI values observed in the snow-covered forests as possible while minimizing inclusion of non-forested pixels. Existing or future MODIS derived vegetation maps may also be used to apply the additional criteria only to forested pixels.

Another possible improvement that has been explored is using MODIS band 7 instead of MODIS band 6 to calculate the NDSI. MODIS band 6 was originally selected because of its history of use in cloud detection. However, the reflectance of some forest species, primarily deciduous species, is much higher than snow in MODIS band 6 which causes forest stands to have lowered NDSI values.

The GeoSAIL was used to model the NDSI values using TM 5 and 7 as surrogates for MODIS band 6 and 7, respectively. For both coniferous and deciduous species, using band 7 results in higher NDSI values, especially for more closed canopies. However, there are two drawbacks to using band 7 in the NDSI calculation. The first is that modeled NDSI values using band 7 for snow-covered coniferous forests are much closer to snow-free conditions than if band 6 is used. Secondly, use of band 7 would require recalculation of the original NDSI threshold. While using MODIS band 7 to calculate the NDSI shows promise for some deciduous canopies, application in a global algorithm is not warranted until comparisons can be made

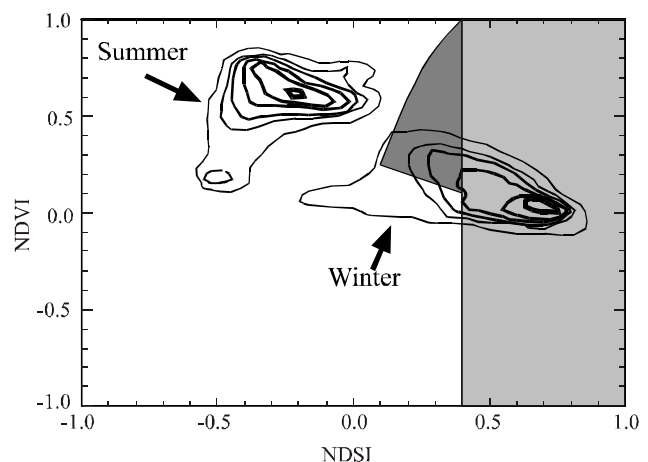


Fig 2: The light gray area indicates NDSI values that are considered snow in the current Snowmap algorithm. The dark gray shaded area indicates the proposed additional field for improved mapping of snow-covered forests. NDSI and NDVI values are contoured for an area surrounding Glacier National Park, Montana, for winter and summer. Thicker lines indicate a higher values of the 2-D probability density function.

with the MAS data in areas where adequate canopy information is available.

Some tree species, most notably black spruce, have very low reflectances in the 1.6 μm wavelength region (MODIS band 6). These low reflectances cause the denominator in the NDSI to be quite small, and only small increases in the visible wavelengths are required to make the NDSI value high enough to be classified as snow. To prevent forest stands with very low visible reflectances from being classified as snow, a 10% reflectance in the green (MODIS band 4) is used as a lower limit. A similar visible criteria has been proposed previously [5]. One potential drawback to using the visible threshold is that some snow-covered forests on slopes that either face away from the sun or are topographically shadowed may have a visible reflectance under ten percent.

ACCURACY ASSESSMENT AND CONCLUSIONS

To quantitatively assess the improvements in snow classification accuracy that are made by the proposed changes, both the original and revised Snowmap algorithms were run on a subsection of five TM scenes surrounding Prince Albert National park. Because validation of actual snow cover extent was not possible, snow cover is assumed to be 100% in the three winter and spring scenes and 0% for the two summer and fall scenes. The algorithms were compared for three forest classes (wet coniferous, dry coniferous, and deciduous). These classes were selected from the land cover map produced from the August 6, 1990 TM scene by F.G. Hall (NASA/Goddard Space Flight Center). Overall, the proposed modifications increase the percentage of total area mapped as snow-covered in the winter scenes and decrease the area incorrectly mapped as snow in the summer and fall scenes (Table 1).

Because forests comprise a large percentage of the

seasonally snow-covered portion of the globe, accurate mapping of snow in forests is essential for producing reliable estimates of global snow cover extent using MODIS. Detection of snow in forests is more difficult than other biomes because a forest canopy obscures and shadows the snow underneath. However, in many instances, snow-covered forests can be distinguished from snow-free forests. Minor changes to the current Snowmap algorithm enable more accurate classification of snow cover in forests without sacrificing its simplicity and computational frugality.

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Table 1: Mapping accuracy of the revised Snowmap algorithm. The first column for each date indicates the percentage of each cover type mapped as snow while values in parentheses indicate the percentage change in area between the revised and original algorithms. Positive values indicate more area mapped as snow in the revised algorithm, and negative values less area mapped as snow in the revised algorithm.

	18-Jan-93		06-Feb-94		29-Mar-95		06-Aug-90		21-Sep-95	
Wet Conifer	99.9	(0.3)	91.6	(15.8)	89.3	(-1.3)	0.00	(0.00)	0.10	(0.00)
Dry Conifer	99.9	(0.1)	93.3	(10.4)	96.4	(0.8)	0.15	(0.07)	0.15	(0.02)
Mixed	99.7	(1.4)	86.1	(37.4)	87.3	(14.8)	0.00	(0.00)	0.00	(-0.04)
Deciduous	99.6	(1.6)	56.6	(33.9)	89.34	(6.3)	0.00	(0.00)	0.00	(0.00)